AU/ACSC/2016

AIR COMMAND AND STAFF COLLEGE

AIR UNIVERSITY

Revitalization of Nuclear Powered Flight

by

Todd C. Dawson, Major, USAF

A Research Report Submitted to the Faculty

In partial Fulfillment of the Graduation Requirements for the Degree of

MASTER OF OPERATIONAL ARTS AND SCIENCES

Advisor: Dr. John Reese

Maxwell Air Force Base, Alabama

May 2016

Disclaimer

The views expressed in this academic research paper are those of the author and do not reflect the official policy or position of the US government or the Department of Defense. In accordance with Air Force Instruction 51-303, it is not copyrighted, but is the property of the United States government.

Table of Contents

Abstract

There has been a lot of talk about the need to develop the third offset, of which human-machine integration seems to have dominated the conversation. The only problem is that our machines are no good unless they have power. Power to fly and run the sensors and weapons the mission requires. Machines for the USAF come in the form of airplanes, which cannot get to the fight without tanker support or stay in the air for a sufficient time. As the USAF looks to the future, it continues to invest heavily in tanker support and operations that are both expensive and not conducive to surviving in a denied environment. We must develop better ways to get our assets to the fight and maintain flight for longer periods of time. I believe one potential solution is to reinvest in nuclear powered flight. The technical challenges seen in the 1950s & 60s could be overcome with today's technology, we just need to set the goal. The ramifications of successfully developing a nuclear propulsion system go far beyond just a military advantage and would serve to revolutionize the way humans travel. This paper takes aim at the feasibility of nuclear powered flight today, along with identifying potential risks and recommendations.

Introduction

[1]As we look at the challenges of today and try to think of what the challenges of tomorrow will be in 2036, it helps to look back in our past to assist in predicting the future. In doing so, imagine being an aviator fighting in the Pacific during World War II, where the great distances of the open ocean are a seemingly insurmountable challenge. Fast-forward a few years to the Cold War, and aviators are confronted with similar challenges of how to attack Russia given the great distances across the Arctic. This issue of how to move over great distances has not changed today and will continue to be a challenge in the future. Today, inflight refueling and more efficient jet engines enable the United States Air Force (USAF) aircraft to truly be a global power. However, as we look to the future, one has to ask, is this sustainable? That is to say, spending billions upon billions of dollars on fuel, acquisition programs to pass fuel, but still being limited in range due to dependency on aerial refueling tankers. In fact, the USAF is so dependent on tanker support that missions have and will fail without it. There has to be a better and more efficient way to fly these great distances or, for surveillance aircraft, stay in the air for as long as possible.

Reflecting on the challenges of yesterday to predict our own future, we can also look to the past to see potential solutions. As you gathered from the title of this research paper, yes it is in fact about revisiting the abandoned 1950-1960's attempts at nuclear powered flight. However, setting aside the technological and political challenges seen at the time, the theories are sound. Place a nuclear reactor or engine on an aircraft and it could, in theory, fly for months on end, giving the aircraft nearly endless range and loiter time. This is of course easier said than done, as the scientists and engineers who attempted it found out. But, given the technological advances of today in nuclear power, the advent of remotely piloted aircraft (RPA), directed energy, and electric engines, is nuclear powered flight more attractive and achievable today? This research paper sets out first to see if the benefits of nuclear powered flight are needed today and tomorrow. Then reviews the first attempt to design a nuclear powered aircraft to gather what challenges they faced in order to see if they can be mitigated or even overcome today or in the near future. One can not only talk about the benefits a potential solution might provide, so an evaluation of potential risks is also reviewed. Finally, given the research into the past, connected with technological advancements of today and the future, recommendations are made regarding how to better posture the USAF to continue to be a global power provider in the future.

Strategic Environment Today/Tomorrow

As stated earlier, the USAF is highly dependent upon jet fuel and tankers in order to project Global Vigilance, Reach and Power. This is as true in 2016 as it will be in 2036, where the USAF will continue to be tasked to operate around the world in both permissive and non-permissive environments. The aircraft the USAF employs today and are looking to develop in the future are highly limited in range, without tanker support. Table 1: USAF Aircraft Range lists several types of aircraft and their max (non-combat) range. Fighter aircraft have limited range of less than 1900 miles, which means that in a permissive environment gives them an effective combat radius of only 500 miles. Switch now to a non-permissive combat environment where you will be burning more fuel faster, and that radius decreases. Aircraft can only go where the tankers or basing can take them. Unless planners are willing to place tankers within range of hostile fire, the targets the USAF needs to engage may not be in the range fighters. Similarly, the limited range of bombers, including that of the B-2 stealth bomber, means that to get from base to target and back requires several refuelings along the way. If your enemy knows where the non-stealth tankers are, they can predict where your aircraft will be coming from.

Even the USAF's ISR platforms the MQ-1/9 have extremely limited ranges, with the exception of the high altitude assets such as the U-2 & RQ-4. With limited range and loiter comes limited range to prosecute a target and dependencies on a refueling network that is not capable of flying in a non-permissive environment.

Table 1: USAF Aircraft Range[2]

Aircraft Type	Aircraft	Range (Unrefueled)
Bomber	B-2 Spirt	5,000 miles
	B-52 Stratofortress	8,800 miles
Fighter	F-35 Lightning II	1,389 miles
	F-22 Raptor	1,850+ miles (Ferry Range)
C2	E-4 National Airborne Operations Center	7,130 miles
ISR	U-2 Dragon Lady	7,000+ miles
Tanker	KC-46 Pegasus	6,500 miles
Airlift	C-5 Galaxy	2,473 miles (max payload)
	C-17 Globemaster III	2,760 miles (max payload)
RPA	MQ-1 Predator	770 miles
	MQ-9 Reaper	1,150 miles
	RQ-4 Global Hawk	10,000 miles
Comparative distances: New York to Los Angeles ~ 2,450 miles Los Angeles to Seoul, Korea ~ 5,950 miles		

Consuming and passing fuel in the air is not cheap. In 2012, the USAF was the largest single consumer of energy in the entire federal government, with a $9 billion power bill, of which 85% or $7.65 billion was for aviation fuel (over 2 billion gallons of fuel at $3.73 per gallon).[3] In 2015, USAF tankers passed more than 1.2 billion gallons of fuel in the air alone at a cost of almost $5 billion.[4] Furthermore, the cost of fuel is always fluctuating. From 2001 to 2012, the price of jet fuel went up almost fourfold and then in late 2015 the United States started seeing record low fuel prices, resulting in challenges of predicting how much money to set aside for fuel costs in the future. And finally, the acquisition cost of tankers is in the billions of dollars. For example, the KC-46A Pegasus has an estimated total acquisition cost of $40.3 billion for 179 aircraft.[5] That is $40 billion on the acquisition alone and historically only accounts for 30% of the overall life cycle cost (acquisition plus operating and maintenance cost), which for the KC-46 would be on the order of $120 billion.

When you add up the fuel, acquisitions, operations and maintenance, training, and personnel, the USAF spends billions of dollars every year to feed aircraft engines. This is the critical point of failure for the USAF to deliver Global Vigilance, Reach and Power. This is true today and will continue to be true through 2036. In fact, given ever increasing demands on the USAF, it might even get worse. Additionally, other than relatively small cost-saving ventures like improving jet fuel efficiency or reducing aircraft weight by getting rid of paper documentation on board, there are no efforts that will drastically change this. There needs to be a better way, and the USAF might look to the past to do it.

Nuclear Powered Aircraft History

On July 16, 1945, the first atomic weapon was detonated in New Mexico, subsequently starting the Atomic Age. In its beginning, the United States' population was very positive about the potential of nuclear power quickly becoming a reality. People thought that some of the benefits would include power so cheap that it would not even be metered and that all modes transportation would be revolutionized. The United States found World War II especially difficult due to the long distances bombers had to travel in order to reach their targets in the Pacific. With the prospects of nuclear power coupled with the necessity to have bombers fly great distances, General Cutis LeMay commissioned the Nuclear Energy Propulsion of Aircraft (NEPA) in 1946. NEPA's task was to oversee investigation into the possibilities for a nuclear powered bomber that could potentially have unlimited range and loiter capabilities.[6]

The concept of military, nuclear-powered flight ran from 1946 to 1964 and was applied to both aircraft and cruise missiles. The goal of this section is not to review in detail the events that transpired during that period, but to highlight some of the technological changes, as well the political changes, which ultimately terminated nuclear powered flight programs. In doing so, the lessons of the past can shed light on some of the potential roadblocks that need to be overcome.

From the technological side, there were several issues that needed to be addressed. First, how do you protect the crew from radiation exposure without adding so much weight that it makes the aircraft unable to fly? Ideas of the time were to distribute the shielding between the reactor, fuselage, and crew compartments in order to protect the crew. Second, was determining if an airframe could house a reactor. The B-36 was selected as it was the largest bomber platform in the inventory, and when carrying a nuclear reactor was renamed the NB-36. Third, was developing a response in the event a nuclear aircraft crashed. For this, marines would fly in a chase plane, and in the event of a crash would secure the area to minimize contamination exposure to non-military personnel. These elements were merged together along with a nuclear reactor, and on September 17, 1955 the first of 47 test flights were made. These test flight never used the nuclear reactor to propel the aircraft, but tested the shielding concepts.

Concurrent to the shielding and airframe testing, the nuclear jet engine concepts were being developed. A normal jet engine produces thrust through the combustion of fuel to produce heat. Similarly, and in theory with less parts and complexity, a nuclear reactor would heat up the air to produce thrust but without combustion or jet fuel. There were two approaches that were developed. First, adopted by General Electric (GE), was a direct cycle concept where the reactor would directly heat the air. This however was considered a dirty system in the sense that air would become irradiated and then exit the aircraft, contaminating the ambient air. The second, adopted by Pratt & Whitney, was an indirect system which would use a medium such as a liquid metal to transfer the heat in a closed system, thus reducing radiation exposure. This concept however, required a great deal of complexity in the form of plumbing and in turn increased the weight.[7]

Small but significant gains were made as the technical challenges were being worked; however, it was the political tension that ultimately terminated the programs. During the almost 20 year span, the United States went through three Presidents: Truman, Eisenhower, and Kennedy. All of these Presidents had concerns about nuclear power being militarized and with the relationship between the military and industry. President Truman separated nuclear weapons from military control in 1951 with the creation of the Atomic Energy Commission. President Eisenhower distrusted the military industrial complex, suspecting companies were pushing technology too far and too fast in order to win bigger contracts. He terminated the WS-125 (nuclear powered bomber), refocusing the need to concentrate on just the reactor. In the wake of, what seemed to be, expanding Soviet superiority in both space and nuclear power, President Kennedy blamed the Eisenhower administration for not putting enough emphasis (funding) on these areas, and made campaign promises to get the United States back on top. After winning the election, President Kennedy received classified briefings showing that the Russians, contrary to public information, did not have a nuclear powered bomber and were not technologically superior. Additionally, following the Cuban Missile crisis, it was his desire to deescalate tension with Russia by signing the nuclear test ban treaty. This terminated all nuclear powered flight, including the development of engines and cruise missiles.[8]

The technological and political challenges with nuclear powered flight lead the governmental leadership to cancel nuclear powered flight because it was too ambitious at the time. Politicians shifted the funding towards simpler and more achievable options, such as aerial tankers and nuclear powered submarines. Although the concept was eventually abandoned, their successes and failures can help guide those who today seek to build upon those lessons with new technological advancements.

Why Revitalize the Nuclear Powered Aircraft Concept Today?

Given the advances in multiple technology areas since the 1960s, coupled with the demand for aircraft to fly further and longer than ever before, nuclear powered aircraft are now more possible, practical, and attractive than ever. These areas include advancements in RPA, directed energy, electric engines, and reactor technology. These are just a few examples of what might be possible today or in the near future and might assist in mitigating the technical challenges seen in the first attempts of nuclear powered flight.

One of the first issues the early nuclear aircraft engineers had to solve was figuring out how to protect the crew from all the radiation being produced by the reactor without adding an exorbitant amount of weight. Today, one potential solution is to remove the crew from the aircraft all together. Developments in RPA technology have enabled them to operate routinely all over the globe, collecting imagery and signals, relaying command and control information, and employing weapons. By removing the human crew, there is no need to protect any occupants from radiation exposure; this does not entirely eliminate the need for shielding, due to maintenance concerns and possible sensor interference. Not to mention the aircraft would become irradiated itself. However, another way RPA technology makes nuclear powered flight more practical today is because of the long flight durations. By removing the flight crew, a nuclear aircraft could sustain flight for months on end while the only crew changes that occur would happen at ground stations. Furthermore, the information collected can be offloaded in flight using satellites to transmit the information. RPA technology today is growing at a rapid rate; it is only limited by the number of aircraft that can be airborne and crews to man the ground station. By extending flight durations, the USAF could simplify this complex problem.

Collecting intelligence information is highly desired, but so is being able to attack a target. The early nuclear aircraft engineers wanted to drop nuclear bombs and cruise missiles. Today, directed energy weapons can create more precise effects by degrading, disrupting and destroying multiple targets; however, they are limited by the amount of power the engine can generate. By placing a nuclear reactor on board, the possibilities for 100 kilowatt plus lasers become more feasible. Thus, opening the target sets of what lasers can impact at greater distances to include self-protection from anti-aircraft fires.[9] Additionally, since the laser is dependent on power and not a munition payload, it could stay aloft with a potentially limitless arsenal. These advancements, in addition to sensor collection, make a nuclear powered aircraft a very practical and capable solution.

The early nuclear aircraft engineers wanted to use typical engine designs, heating air to produce thrust. Doing so was complicated because you needed to transfer the heat. But, what if instead you used the reactor just to produce electrical power and use electric engines for thrust? Today's electric powered aircraft are cheaper to run and maintain, quieter, and vibrate less than jet fuel powered aircraft. All are qualities that the USAF would like in their own fleet. Additionally, an electric engine provides greater acceleration because the power is applied instantaneously without any need to build up heat to produce thrust. And speaking of heat, the heat and noise signature of an electric engine are significantly less than that of a combustion engine. Just like in today's cars, batteries limit the range a driver or pilot can travel on a single charge. What if a reactor was installed vice a battery? A nuclear powered electric engine propelled aircraft might be just what the USAF needs to fly great distances at a more reasonable price.

Thus far, technological advances in RPAs, directed energy and electric engines have increased the practicality of a nuclear powered aircraft today. However, a reactor or engine is still needed to harness the atomic energy while inflight. The final technological advances are in the realm of compact nuclear fusion and nuclear powered jet engines.

Early and current nuclear energy concepts use fission, which is the process of splitting atoms into two smaller fragments. The result is an explosion of heat that can be converted into usable energy. Conversely, in the same manner that stars produce energy, fusion happens when two or more atoms collide at a very high speed and join to form a new nucleus. When this happens, they release large amounts of energy because the mass of the combination is less than the sum of the masses of the individual atoms.[10] It is estimated that the energy potential is about one million times more powerful than a chemical reaction and 3-4 times more powerful than a fission reaction.[11] In capitalizing many years of fusion research, the Lockheed Martin Skunk Works is developing an approach to compact fusion using a high beta concept. Their concept uses magnetic field pressure to make devices 10 times smaller than previous concepts. By their estimates, the reduction in size replaces a device that must be housed in a large building with one that can fit on the back of a truck and produce enough power for a small city of up to 100,000 people or about 100 megawatts. Additionally, their compact fusion technology could potentially be applied to an aircraft such as the C-5, which in turn would be able to fly for about one year on a few bottles of hydrogen.[12]

In July 2015, Boeing received a patent for a Laser Fusion Jet Engine. The concept basically works by placing a fuel pellet into a cavity, such as the combustion chamber of a current engine, then laser detonating the pellet causing fusion thus resulting in energy being released. The energy released produces thrust as well as drives turbines that produce electricity to fire the laser and power the aircraft electrical systems.[13] Just because Boeing has received a patent for their concept does not mean that Boeing is actively developing this technology; however, the free-electron laser and fuel pellets are two sub-components that are in development. Boeing has been developing free-electron lasers for use onboard Navy ships since at least 2009. Free-electron lasers are like regular lasers except they use the vibration of electrons to generate light and can be tuned across a wide frequency range from microwaves all the way through x-rays.[14] For the Navy, this technology has potential applications as an anti-aircraft and missile directed energy weapon. The laser fusing of fuel pellets on the other hand is being worked but is far from ready for applications inside an aircraft jet engine. The Lawrence Livermore National Laboratory's National Ignition Facility in San Francisco has demonstrated that they can fuse nuclear pellets by using lasers. However, the amount of energy released has only been equal to that of the amount of energy the laser is putting in. The facility continues to test the concept, but due to technical setbacks has had funding reduced until further research can be accomplished.[15]

Potential Risks

The technological advancements discussed are encouraging when thinking about the feasibility and practicality of a nuclear powered aircraft today. However, like the early engineers discovered, this task is easy in theory but difficult in practice. Not to mention we are talking about putting a nuclear reactor on an unmanned aircraft with advanced sensors, lasers, and electric engines giving the operator the ability to fly anywhere and for as long as desired with a limitless kinetic payload. Setting aside the technical challenges this type of project would entail, there are the seemingly endless political risks and public scrutiny. A weapon like this would be highly provocative to our adversaries and may not be well received by our allies. Additionally, United States oil lobbyists would not like billions of dollars being removed from their market. They would likely petition their consortium of elected representatives to strike down any proposal that would cause such a ruffle in their market. Furthermore, the potential public outcry over the perceived dangers of nuclear power would also mount a serious threat to such a proposal. The most common questions being, what if the plane crashes or is high-jacked? Will it cause a nuclear explosion or contaminate the crash site? All of these safety questions would need to be addressed and overcome as a program is developed.

Recommendations

After reviewing the desired need for long distance and high duration flights, the lessons learned from previous attempts at nuclear powered flight coupled with today's technological advancements, it is my opinion that the USAF should take a lead role into pursuing atomic flight. To do so should be incremental, first by tasking the Air Force Research Laboratory (AFRL) in cooperation with other service and national laboratories to take a new look at the potential and feasibility of nuclear powered flight today. Additionally, AFRL should look at how detectable a nuclear powered aircraft might be and look at costs to intergrade onto existing or developmental aircraft. In doing so, a review can make an updated assessment and propose a way for the future. Some additional areas might include: what would the detectability be for a nuclear powered aircraft and how much would it cost to intergrade onto existing or a potentially new aircraft. That way to the future might be that it is not ready today, to which a review on a reoccurring basis should be conducted. Additionally, in conducting the review, the USAF would network into private industry, building partnerships that could benefit both government and industry through funding and sharing technologies. If the USAF desires a nuclear powered flight capability, it will need to sell the idea to the politicians as well as the public. By partnering with industry, they can further develop the technology to bring it to everyday life in America, thus making it more palatable to the greater public. Additionally, the USAF alone cannot overcome the potential roadblocks from big oil companies. By working to get a positive public opinion the USAF could entice political leadership to protect the application for a military gain. The USAF would also need to work directly with Congress to ensure potential laws and treaties are modified to prepare for nuclear powered flight.

Conclusion

Ever since the dawn of flight, aviators have dreamed of how to fly further and stay in the air longer. Spring forward to the atomic era and we find scientists and engineers highly optimistic about the potentials of harnessing the power of the atom. Coupling the aviators' desire and the power of the atom was no trivial task in the 1950's and 60's and is still no easier or less complex today. But today and as we look to the future, the USAF needs to re-look at the concept of nuclear powered flight incorporation with the advancements in RPA, directed energy, electric engines, and reactors. This might seem like science fiction, but it might end up being completely practical and feasible today or in the near future. The USAF, the population and leadership need only give it a serious, unbiased review. In doing so, they might not think that a nuclear powered UAV with lasers is that far out there.

[1] I wish to thank Major Shawn Littleton and Major James Caldwell for their thoughtful comments and suggestions. All errors found herein are my own.
[2] Air Force Association. "2015 USAF Almanac."
[3] Insinna, Valerie. "Air Force Making Headway on Fuel Efficiency Goals."
[4] James, Deborah. "Fiscal Year 2017 Air Force Posture Statement."
[5] Defense Acquisition Management Information Retrieval System. "Cost and Funding for KC-46 A from SAR Dec 2014."
[6] Hedges, John, host. "Nuclear Airplane (Season 1, Episode 4)."
[7] Ibid.

[8] Hedges, John, host. "Nuclear Airplane (Season 1, Episode 4)."
[9] Wang, Brian. "US Could Ramp Up Military Lasers by Ten Times to 300 kilowatts by 2018."
[10] Georgia State University Department of Physics and Astronomy. "Nuclear Fusion."
[11] Lockheed Martin. "Compact Fusion."
[12] Ibid.
[13] Ackerman, Evan. "Boeing Patents Laser Nuclear Fusion Jet Engine."
[14] Ibid.
[15] Courtland, Rachel. "Laser Fusion's Brightest Hope."

Bibliography

Ackerman, Evan. "Boeing Patents Laser Nuclear Fusion Jet Engine." IEEE Spectrum. July 10, 2015. Accessed March 8, 2016. http://spectrum.ieee.org/tech-talk/energy/nuclear/boeing-patents-laser-nuclear-fusion-jet-engine.

Air Force Association. "2015 USAF Almanac." Air Force Magazine. May 2015.

Colon, Raul. Flying on Nuclear, The American Effort to Build a Nuclear Powered Bomber. The Aviation History On-Line Museum. August 6, 2007. Accessed February 16, 2016. http://www.aviation-history.com/articles/nuke-american.htm.

Courtland, Rachel. "Laser Fusion's Brightest Hope." IEEE Spectrum. March 27, 2013. Accessed March 8, 2016. http://spectrum.ieee.org/energy/nuclear/laser-fusions-brightest-hope.

Denison Mines. "Uranium Industry: Uranium Prices." Accessed March 8, 2016. http://www.denisonmines.com/s/Uranium_Prices.asp.

Frenkel, Karen. Resuscitating the Atomic Airplane: Flying on a Wing and an Isotope. Scientific America. December 5, 2008. Accessed February 16, 2016. http://www.scientificamerican.com/article/nuclear-powered-aircraft/.

Georgia State University Department of Physics and Astronomy. "Nuclear Fusion." Hyper-Physics. Accessed March 8, 2016. http://hyperphysics.phy-astr.gsu.edu/hbase/nucene/fusion.html.

Gohardani, Amir. Challenges of Future Aircraft Propulsion. Progress in Aerospace Sciences. Volume 47, Issue 5, July 2011, Pages 369–391. Accessed February 16, 2016. http://www.sciencedirect.com/science/article/pii/S0376042110000497.

Hedges, John, host. "Nuclear Airplane (Season 1, Episode 4)." In *Planes That Never Flew*. Discovery Channel. 2003. Accessed March 10, 2016. https://www.youtube.com/watch?v=xb7uZQ1_n4w&index=1&list=PLmt0cEgGTSM93MVuMiZYL_zqqRGLUhICC

Insinna, Valerie. "Air Force Making Headway on Fuel Efficiency Goals." National Defense Magazine. June 2013. Accessed on March 9, 2016. http://www.nationaldefensemagazine.org/archive/2013/June/Pages/AirForceMakingHeadwayonFuelEfficiencyGoals.aspx.

James, Deborah. "Fiscal Year 2017 Air Force Posture Statement." United States Senate Committee on Appropriations. February 10, 2016.

Lockheed Martin. "Compact Fusion." Accessed March 8, 2016. http://www.lockheedmartin.com/us/products/compact-fusion.html.

Makhijani, Arjun. Plutonium as an Energy Source. Institute for Energy and Environmental Research. February 1997. http://www.ieer.org/ensec/no-1/puuse.html.

National Aeronautics and Space Administration. Welcome to the Beginner's Guide to Propulsion. Accessed February 16, 2016. https://www.grc.nasa.gov/www/k-12/airplane/bgp.html.

Norris, Guy. Skunk Works Reveals Compact Fusion Reactor Details. Aviation Week & Space Technology. October 15, 2014. Accessed February 16, 2016. http://aviationweek.com/technology/skunk-works-reveals-compact-fusion-reactor-details.

Defense Acquisition Management Information Retrieval System. "Cost and Funding for KC-46 A from SAR Dec 2014." Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics. Accessed March 9, 2016. https://ebiz.acq.osd.mil/DAMIR/PurviewNew/PurviewDefault.aspx?progId=150635

Pomeroy, Ross. "Why Not Nuclear-Powered Aircraft?" Real Clear Science. July 31, 2014. Accessed February 16, 2016. http://www.realclearscience.com/blog/2014/07/why_not_nuclear-powered_aircraft.html.

Schilling, David. Boeing's New Laser Nuclear Fusion Powered Aircraft. Industry Tap. July 14, 2015. Accessed February 16, 2016. http://www.industrytap.com/boeings-new-laser-nuclear-fusion-powered-aircraft/29983.

Seligman Lara, Pratt, GE Battle for Future of Military Engines. Defense News. October 10, 2015. Accessed February 16, 2016. http://www.defensenews.com/story/defense/air-space/2015/10/10/pratt-ge-battle-future-military-engines/73201826/.

United States General Accounting Office. Review of Manned Aircraft Nuclear Propulsion Program. 28 February 1963. Accessed February 22, 2016. http://fas.org/nuke/space/anp-gao1963.pdf/.

Wang, Brian. "US Could Ramp Up Military Lasers by Ten Times to 300 kilowatts by 2018." Next Big Future. 04 March 2015. Accessed March 8, 2016. http://nextbigfuture.com/2015/03/us-could-ramp-up-miliary-lasers-by-ten.html.

Weintz, Steve. America's Crazy Attempts to Build Nuclear-Powered Aircraft. The National Interest. July 17 2015. Accessed February 16, 2016. http://www.nationalinterest.org/feature/americas-crazy-attempts-build-nuclear-powered-aircraft-13352?page=2.

Wendt, Gerald. A Scientist Previews: The First Atomic Airplane. Popular Science Monthly October. 1951. Pp 98-102. Accessed February 16, 2016. https://books.google.com/books?id=OSEDAAAAMBAJ&pg=PA98&dq=popular+science+1951+atomic+aircraft&hl=en&ei=dgzFTP-MF8innQeCs-T4CQ&sa=X&oi=book_result&ct=result&resnum=1&ved=0CC0Q6AEwAA#v=onepage&q&f=true.